CHAPTER 4

TERMINAL BALLISTICS

by

James L. Summers and B. Pat Denardo

NASA-Ames Research Center

TERMINAL BALLISTICS

James L. Summers and B. Pat Denardo

4.1 INTRODUCTION

Studies of terminal ballistics, or impact and penetration phenomena, have been motivated by interests in subjects as diverse as meteor craters on the moon and planets, armoring of military vehicles, meteoroid protection of space vehicles, and solid state physics of materials at extremely high pressures. To study impact, it is necessary to have an impacting object, the projectile, in high-velocity, relative motion compared to the target object or material. Aside from the study of natural impact craters, such as the aforementioned meteor craters, the most evident method of studying such phenomena is to set the projectile in motion in a gun, and to direct it at the target under controlled conditions of velocity and environment. Other means of putting the projectile in motion can be devised - e.g., use of high explosives, use of rockets, use of electrostatic forces to accelerate small particles - but it seems clear that the gun and the ballistic range comprise the basic laboratory approach to impact studies.

Classification of impact investigations by velocity ranges has some value in both discussions of the phenomena which control the impact process and in equipment needed to perform the research. In the lowest velocity range, within usual experience, the impacts may be either elastic or inelastic and penetration or permanent damage may or may not occur. This range is below the velocities generally associated with guns and need not concern us. The range of moderate velocities, associated with usual guns, is a range in which damage and penetration occur, but strong shock waves are not formed in the target material. The higher velocity range, referred to as the hyper-velocity impact range, is characterized by the formation of very strong shock waves in the target, and pressures measured in millions of atmospheres. Special high performance guns (light gas guns) and partially evacuated ranges are required to work in this regime.

While some elements of the ballistic range used for impact studies are the same as those discussed in Chapters 2 and 6, namely the guns and part of the instrumentation, other elements are essentially different and specialized. Spark photographs are used here primarily to measure the velocity and attitude of the model in flight so as to define these conditions at the instant of impact. The bulk of the instrumentation will be grouped around the target, and may include ultra high-speed cameras to time resolve the externally visible impact processes, luminosity detectors, and other electro-magnetic emission detectors. Simple or multiple ballistic pendulums may be provided to measure the momentum components of the impact. Special screens placed to catch and record the distribution of material ejected either forward or backward from the impact region may be installed. And, of course, primary emphasis is put on target recovery, measurement, and examination.

In this chapter, we will discuss these techniques which are special to the performance of impact studies. We will also, for completeness, describe various arrangements of the basic equipment essential to doing impact work in ballistic ranges. Since the nature of the research determines the kind of instrumentation needed, we will begin by briefly reviewing the kinds of research objectives which may be satisfied in impact studies.

4.2 AREAS OF IMPACT RESEARCH

Specific areas of hypervelocity impact research that can be studied in the ballistic range include the basic phenomenology of cratering, impact performance of complex space structures, and the properties of materials at very high pressure.

In studies of the phenomenology of cratering, a further classification is made on the basis of the thickness of the target specimen, because the phenomena observed depend very markedly on this parameter. Targets may vary from thicknesses of only a fraction of the characteristic dimension of the impacting projectile, to very thick, many times greater than this dimension, and are classified as thin, thick, and semi-infinite. Target materials include virtually all known substances; metals, minerals, plastics, and organic substances. The proceedings of several symposia covering this area of research are listed in References 4.1 through 4.8.

A second area of research, the evaluation of the performance of complex space structures when impacted by very high speed particles, is primarily a matter of assessing how much damage results from the impact of a known mass at a known speed into a variety of structures. Of course, tests of this kind often suggest improvements in design which increase the structure's resistance to damage. Examples of space structures include vehicle structural components, fuel cells, solar cells, heat shields, propulsion units, and space-suit materials. References 4.9 through 4.12 describe the results of some of the many experiments in this field.

The argon flash-gap technique makes use of the fact that this gas will glow brightly when strongly shocked. The following description of the technique is greatly simplified and is meant to illustrate the principle only. The test sample to be impacted is constructed with a groove of fixed width, but of tapering depth, which laterally traverses the rear face of the sample. As the shock wave proceeds into the sample from the impacted face, it will reach the deepest part of the groove first and then proceed laterally along the groove bottom to the shallowest part. The shock-wave velocity in the test sample can then be determined from (1), the angle between the plane of the shock-wave and the groove bottom, and (2), the lateral closing velocity along the groove bottom. This lateral movement of the shock-wave is made visible by inserting a transparent strip of acrylic plastic (Lucite or Plexiglass) into the groove but spaced away from the bottom to provide a gap of a fraction of a millimeter. Argon gas is flooded into this gap. As the shock-wave proceeds along the groove, the bottom moves as a free surface and generates a shock-wave in the argon gas, causing it to glow brightly. When the free surface strikes the acrylic strip, the acrylic becomes opaque and acts as a sharp cutoff optical shutter. Thus, a streak camera viewing the test sample from the rear and with its film moving normal to the groove, would record a sharply defined streak on the film. If appropriate fiducial marks are located on the rear of the test sample for film calibration purposes, then the lateral velocity of the shock-wave, and hence the propagation velocity of the shock-wave, can be computed from the camera speed and film-streak angle. A second acrylic strip with an argon flash gap, but located on the plane portion of the test sample rear surface and at an angle to it so that the closing distance from the free surface varies along its length, provides similar information for determining the free-surface velocity. The pin-gage and flash-gap techniques give experimental results in substantial agreement. Both methods are described in detail in Reference 4.13.

Many special techniques have been developed to study impact phenomena. Among these are the methods wherein substitute materials are employed for the projectile, target, or both. Particulate material is often used for the target material because binders of different strengths can be employed to vary the strength of the target from a few pounds per square inch to several thousand pounds per square inch. Also, if the targets are made up of colored layers of material, the movement of the target material caused by the impact of a projectile is readily traced as can be seen from Figure 4.7. References 4.19 and 4.20 describe the results of some investigations where particulate material has been used to study the impact process.

Another scheme devised to study cratering phenomena at meteoric velocities, beyond the capability of the launching devices, is to substitute for the desired test projectile, a simulating projectile made of denser material. For a given impact velocity, this denser projectile will produce a higher shock pressure and thus be somewhat representative of the desired projectile impacting at a higher velocity. Such a simulation results in cratering data suitable for engineering purposes, but because of the fundamental differences in the Hugoniot properties of the desired test projectile and its simulating counterpart, one cannot duplicate accurately all aspects of the cratering process.

While the above discussion is not extensive, it indicates some of the key techniques employed in laboratory studies of impact. Certainly, many additional experimental techniques have been devised, and others will be, to study particular features of impact problems. The reader is referred to the references given for more detailed discussions of some of these techniques.

REFERENCES

4.1 Proceedings of the First Hypervelocity Impact Symposium, The Rand Corp., Santa Monica, Calif., early in 1955.

4.2 Proceedings of the Second Hypervelocity Impact Symposium, Naval Research Laboratory, Washington, D.C., May 1957.

4.3 Proceedings of the Third Hypervelocity Impact Symposium, Armour Research Foundation of the Illinois Institute of Technology, Chicago, Illinois, October 7-9, 1958.

4.4 Proceedings of the Fourth Hypervelocity Impact Symposium, Air Proving Ground Center, Air Research and Development Command, US Air Force, Eglin Air Force Base, Florida, April 26-28, 1960.

4.5 Proceedings of the Fifth Hypervelocity Impact Symposium, Colorado School of Mines, Denver, Colorado, October 30-31, November 1, 1961.

4.6 Proceedings of the Sixth Hypervelocity Impact Symposium, The Firestone Tire and Rubber Co., Cleveland, Ohio, April 30, May 1-2, 1963.

4.7 Proceedings of the Seventh Hypervelocity Impact Symposium, The Martin Company, Tampa, Florida, November 17-19, 1964.

4.8 Proceedings of AIAA Hypervelocity Impact Conference, Cincinnati, Ohio, April 30-May 2, 1969.

4.9 Nysmith, C. Robert; Summers, James L. *Preliminary Investigation of Impact on Multiple-Sheet Structures and an Evaluation of the Meteoroid Hazard to Space Vehicles.* NASA TN D-1039, 1961.

4.10 Nysmith, C. Robert; Summers, James L. *An Experimental Investigation of the Impact Resistance of Double-Sheet Structures at Velocities to 24,000 Feet per Second.* NASA TN D-1431, 1962.

4.11 Nysmith, C. Robert. *Penetration Resistance of Double-Sheet Structures at Velocities to 8.8 km/sec.* NASA TN D-4568, 1968.

4.12 Summers, James L.; Nysmith, C. Robert. *The Resistance of a Variety of Composite Space Structures to Hypervelocity Impact.* Proceedings of AIAA 5th Annual Structures and Materials Conference, Palm Springs, April 1-3, 1964, pp.386-393.

4.13 Seitz, Frederick; Turnbull, David (Editors). *Solid State Physics.* Academic Press, Inc., New York and London. Vol.6, 1958, pp.1-63.

4.14 Denardo, B. Pat; McGee, James E. *Simplified Rapid Opening Mechanical Gate Valve.* The Review of Scientific Instruments, Vol.37, No.10, October 1966, p.1403.

4.15 Nysmith, C. Robert; Summers, James L.; Denardo, B. Pat. *Investigation of the Impact of Copper Filaments into Aluminum Targets at Velocities to 16,000 Feet per Second.* NASA TN D-1981, 1964.

4.16 Fish, Richard H. *The Penetration of Porous Projectiles in Aluminum and Plastic Targets.* NASA TN D-4505, 1968.

4.17 Kinard, William H.; Collins, Rufus D. Jr. *A Technique for Obtaining Hypervelocity Impact Data by Using the Relative Velocities of Two Projectiles.* NASA TN D-724, 1961.

4.18 Denardo, B. Pat. *Measurements of Momentum Transfer from Plastic Projectiles to Massive Aluminum Targets at Speeds up to 25,600 Feet per Second.* NASA TN D-1210, 1962.

4.19 Gault, Donald H.; Quaide, William L.; Oberbeck, Verne R. *Impact Cratering Mechanics and Structures.* Presented at the Conference on Shock Metamorphism of Natural Materials, Goddard Space Flight Center, Greenbelt, Maryland, April 1966.

4.20 Quaide, William L.; Oberbeck, Verne R. *Thickness Determination of the Lunar Surface Layer from Lunar Impact Craters.* J. of Geophys. Res., Vol.73, No.16, August 15, 1968, pp.5247-5270.

Fig. 4. 1 Ballistic range for impact research

Fig. 4. 2 Vertical ballistic range (lowered to the horizontal position for maintenance)

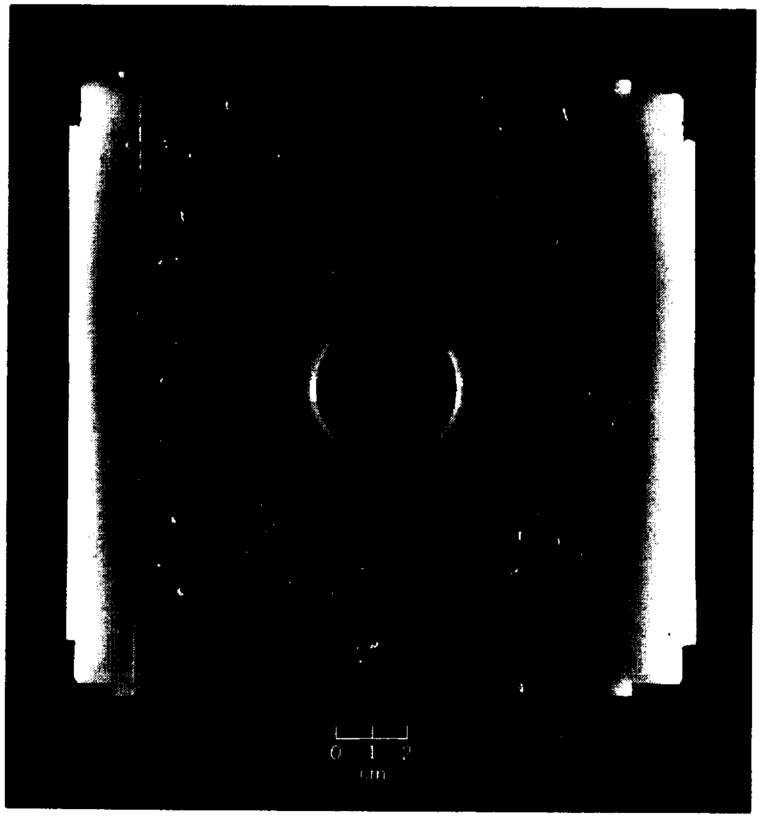

Fig. 4. 3　Ejecta pattern on catcher

Fig. 4. 4　Spray pattern on catcher

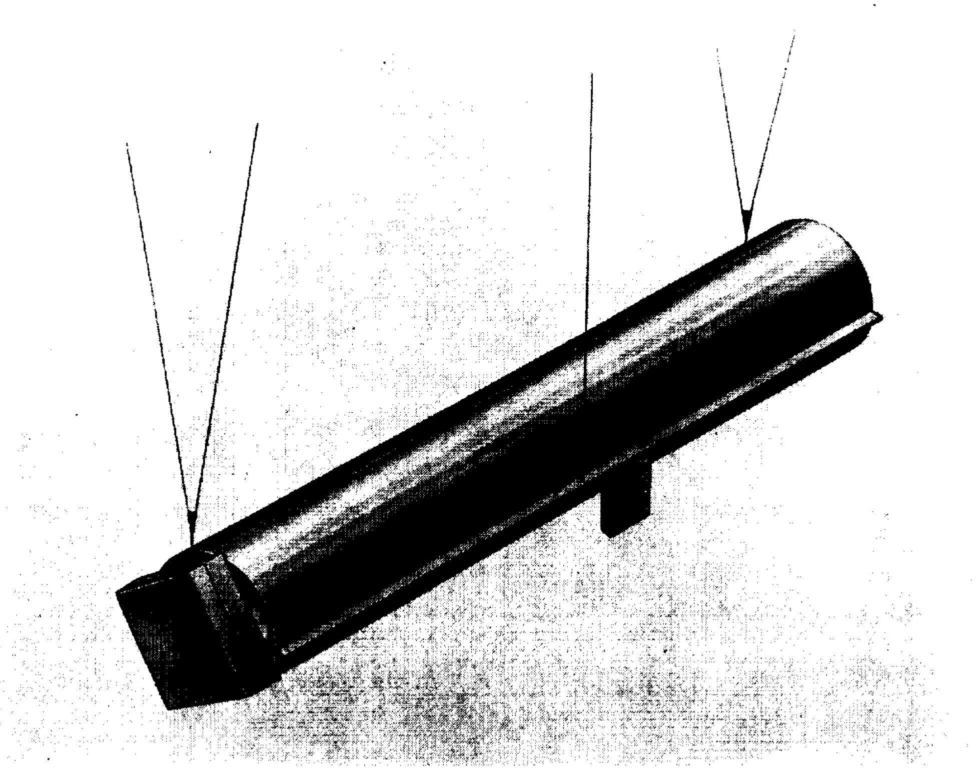

Fig.4.5 Classical five-wire ballistic pendulum

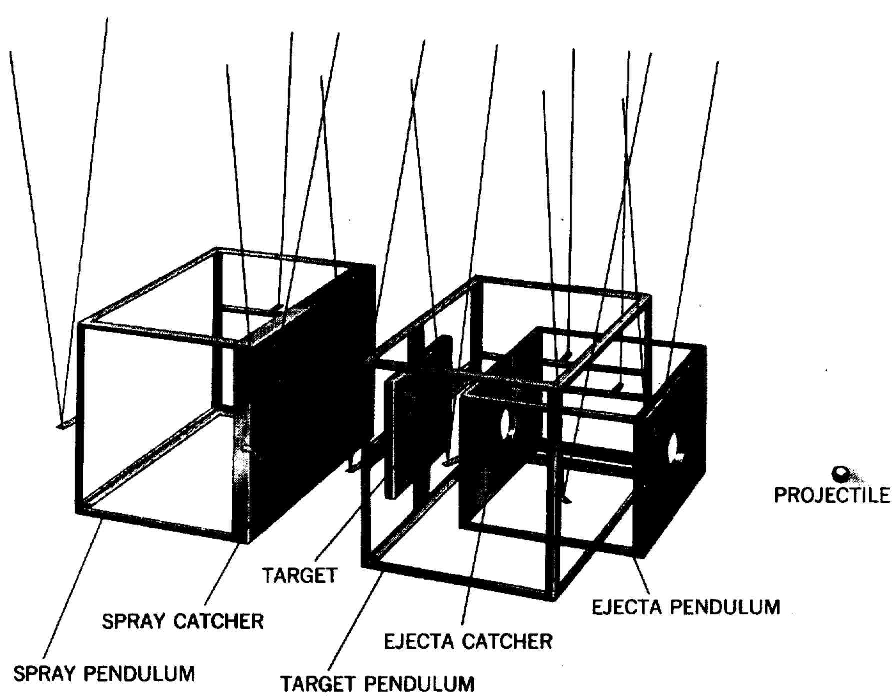

Fig.4.6 Multiple-ballistic-pendulum system

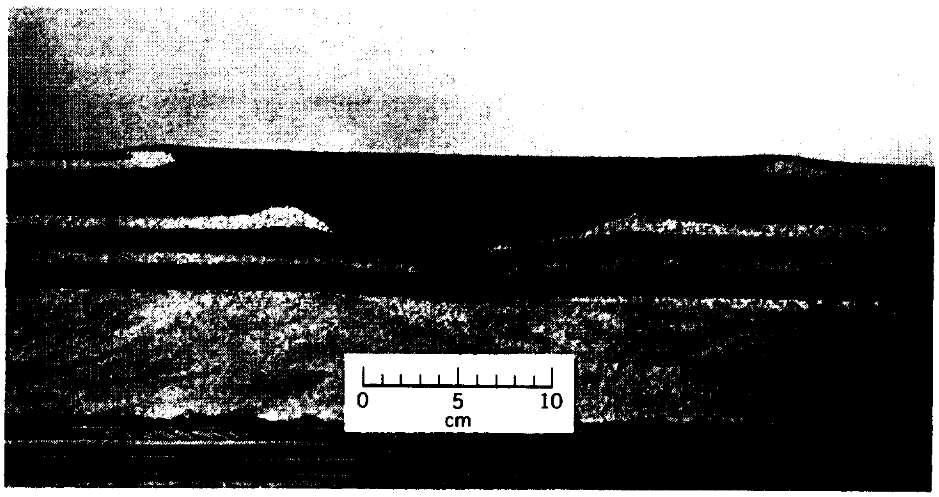

Fig.4.7 Sectioned particulate target